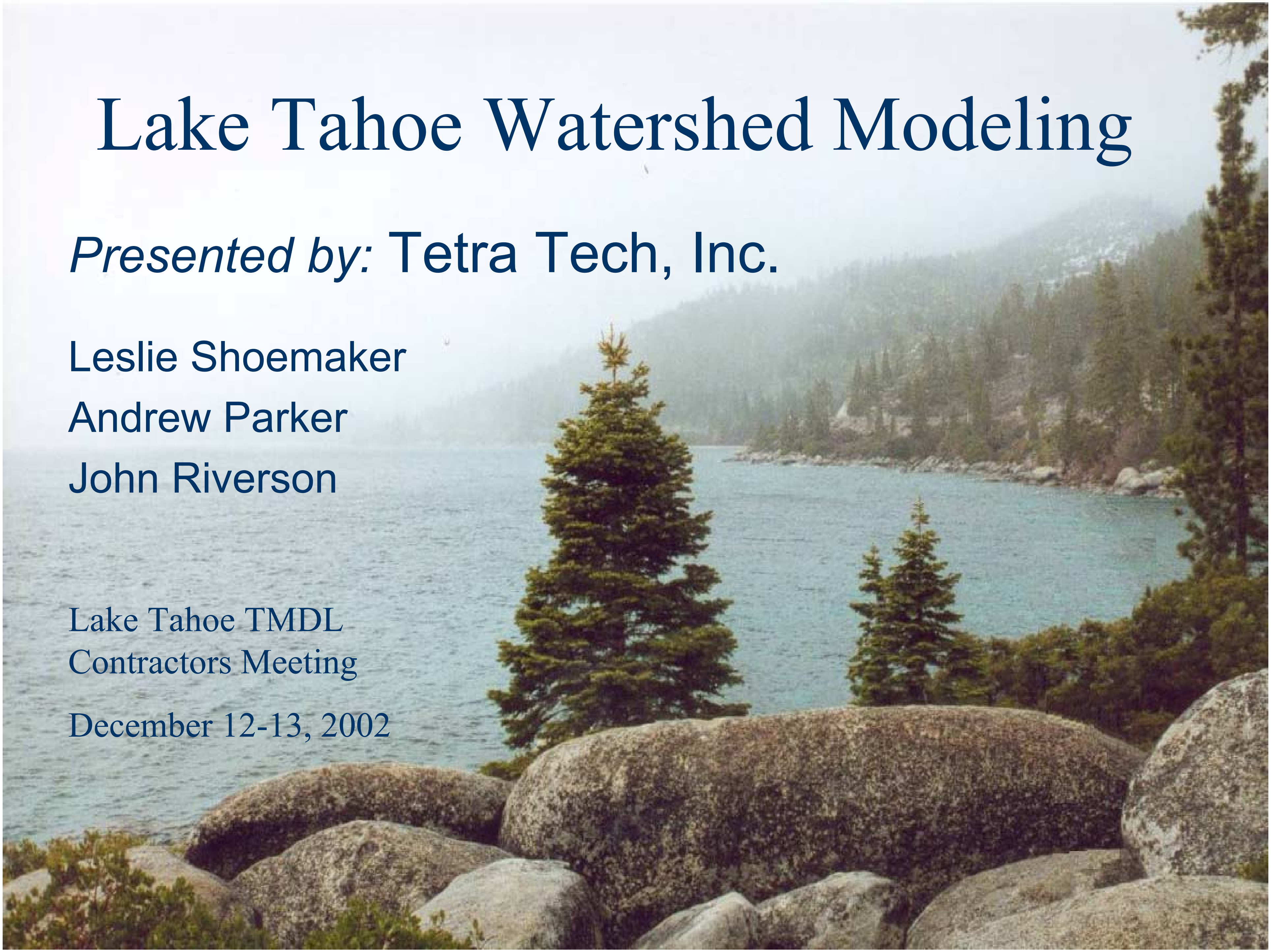


Lake Tahoe Watershed Modeling

Presented by: Tetra Tech, Inc.

Leslie Shoemaker

Andrew Parker

John Riverson

Lake Tahoe TMDL
Contractors Meeting

December 12-13, 2002

Watershed Modeling Goals

- Provide estimates of watershed loading of sediment and nutrients to Lake Tahoe
- Provide input to the Lake Clarity Model
- Evaluate management scenarios to meet loading targets
- Estimate TMDL allocation components

Integration of research results

Relationship to Other Tasks

Physical Characteristics:
- Meteorological
- GIS – land use…
- Topography
- Stream characteristics
- Monitoring

Statistical Analysis

Watershed Modeling

BMP Analysis

Lake Model

***External Source Inputs*:**
- Atmospheric
- Groundwater
- Other sources

Evolution of the Watershed Model

Phase I

- Model Scoping with Workgroup Input
- Data Compilation (historic, ongoing)
- Preliminary Model Configuration and Calibration
    - Hydrology
    - Sediment
    - Nutrients
- Preliminary TMDL Analysis

Phase II

- Model Reconfiguration Using Research Results
- Model Recalibration and Validation/Verification
- Loading Alternative Evaluation
- TMDL Analysis

Watershed Model Project Timeline

TASK	2002		2003				2004				2005				Needs from Other Group Members
	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	
1. Hydrology Model Development															
1.1 Subwatershed Delineation															s/w monitoring site delineations, Tahoe Basin subcatchments
1.2 Meteorological Data Processing															meteorological grid, time series data files @ ground surface (either complete or example/partial)
1.3 Calibration															groundwater analysis results (flow), flow gage data, stream cross-sections, BMP hydrologic effects
2. Sediment Model Development															
2.1 Data Compilation															tributary and historic s/w monitoring data
2.2 Model Formulation Selection															stream channel erosion results, fine particles analysis results, input req'mts to lake clarity model
2.3 Calibration															calibration data set selection
3. Nutrient Model Development															
3.1 Data Compilation															historical tributary and s/w monitoring data, s/w monitoring data
3.2 Model Formulation Selection															
3.3 Calibration															calibration data set selection
4. Preliminary TMDL Analysis															
5. Model Refinement and Verification															
5.1 Model Refinement - Nutrients															wq statistical analysis results, atmospheric deposition analysis results
5.2 Model Refinement - BMPs															BMP analysis results
5.3 Verification															s/w monitoring data
6. TMDL Analysis															

Model Selection

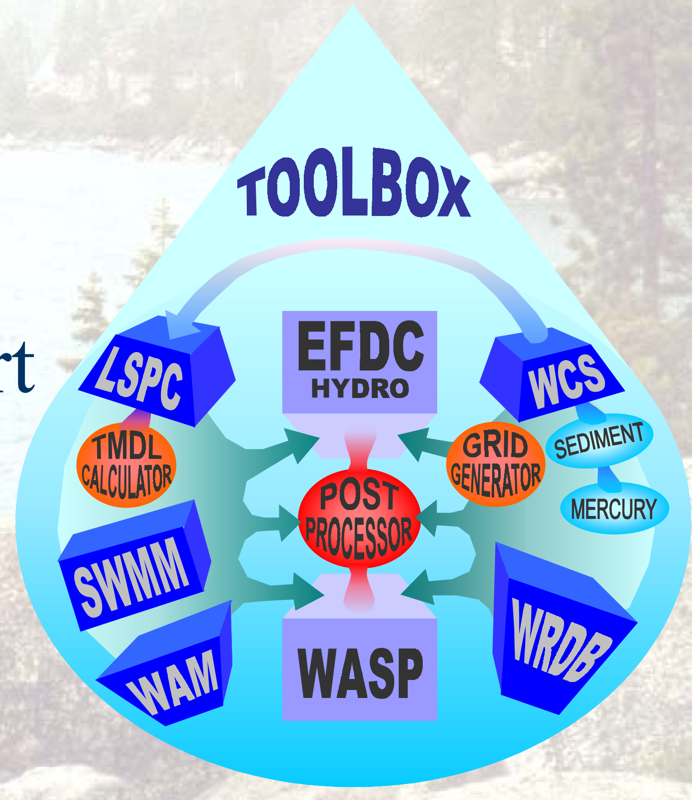
- Apply EPA's Loading Simulation Program in C++ (LSPC), a dynamic watershed model, to simulate hydrologic processes, erosion and sediment transport, and nutrient accumulation/transport for the Tahoe Watershed

LSPC

- Loading Simulation Program, C++
- Streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for pervious and impervious land flow and pollutant transport, coded with Visual C++ in an object-oriented environment
- Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access, and Excel
- Key watershed modeling component of the TMDL Toolbox (developed and maintained by EPA Region 4 with support from Tetra Tech)
- TMDLs successfully developed in AL, MS, SC, GA, CA, KY, TN, WV, VA, MD, AZ, OH, Puerto Rico, and U.S.V.I.

TMDL Toolbox Overview

- Collection of models, modeling tools, and databases that have been used historically in determination of TMDLs
- Facilitates exchange of data among all components
- Developed modularly to support future expansion
- Public domain

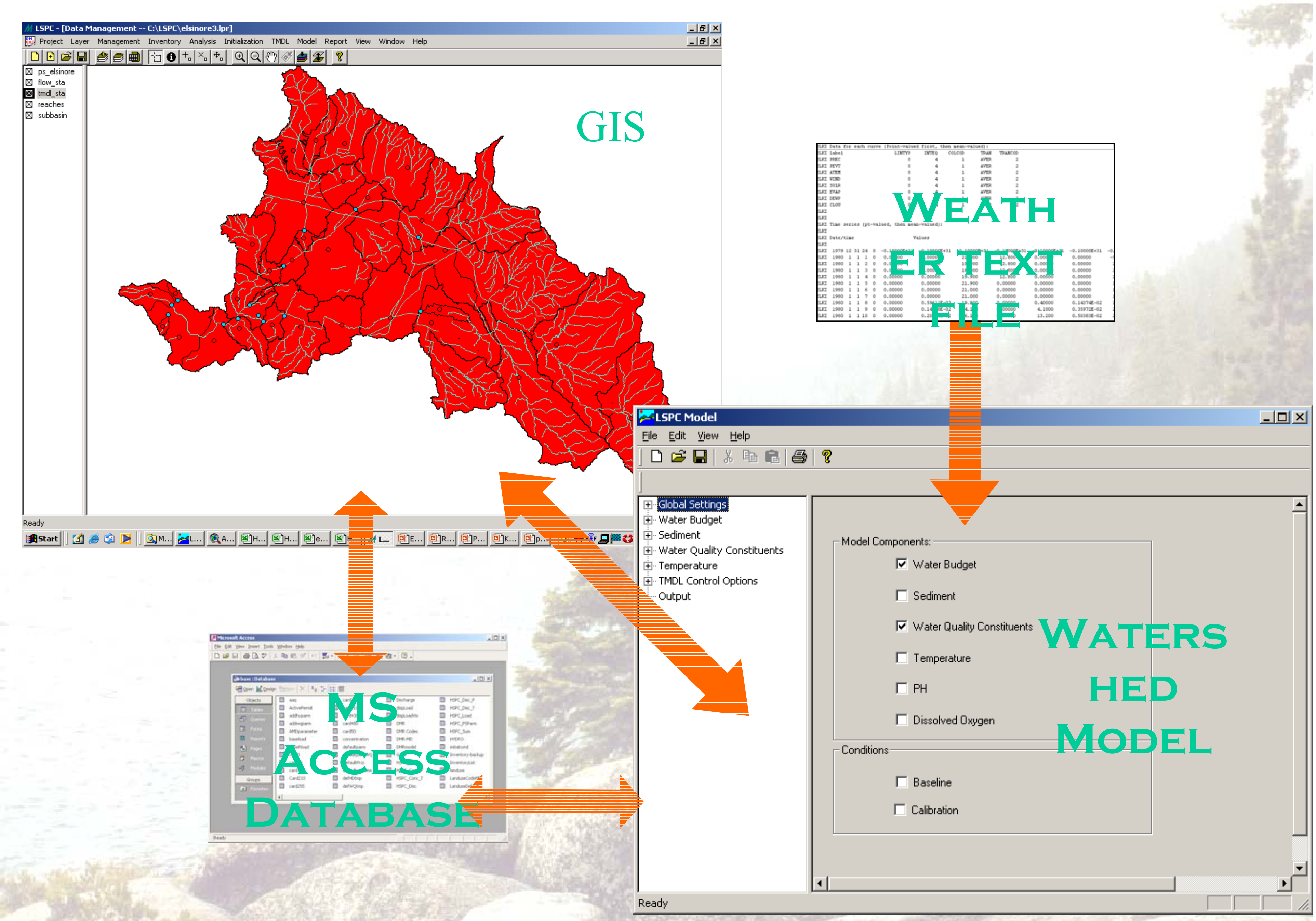


Key Considerations Used in the Design of LSPC

- Potential for very large-scale modeling (e.g. HUC-wide or Statewide)
- Increase efficiency of model setup and execution (eliminate unnecessary, repetitive user input, hence minimizes the chance of human error)
- Simplify model output
- Tailored for TMDL development
  - Handles potential nonpoint and point sources
  - Calculation tools
  - Archival system
- Highly adaptable design and programming architecture that allows for modular additions and/or improvements (e.g., hydraulic modification, BMP simulation)

LSPC Modules

- GIS
- Data management
- Data inventory
- Data analysis
- Watershed model
- Model results analysis


LSPC - [Data Management -- C:\LSPC\elsinore3.lpr]
Project Layer Management Inventory Analysis Initialization TMDL Model Report View Window Help
ps_elsinore
flow_sta
tmdl_sta
reaches
subbasin
Ready
GIS
WEATH
ER TEXT
FILE
LSPC Model
File Edit View Help
Global Settings
Water Budget
Sediment
Water Quality Constituents
Temperature
TMDL Control Options
Output
Model Components:
Water Budget
Sediment
Water Quality Constituents
Temperature
PH
Dissolved Oxygen
Conditions
Baseline
Calibration
Ready
WATERS
HED
MODEL
MS
ACCESS
DATABASE

Hydrology Model Development

TASK	2002		2003				2004				2005			
	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
1. Hydrology Model Development														
1.1 Subwatershed Delineation														
1.2 Meteorological Data Processing														
1.3 Calibration														

Key considerations and data needs:

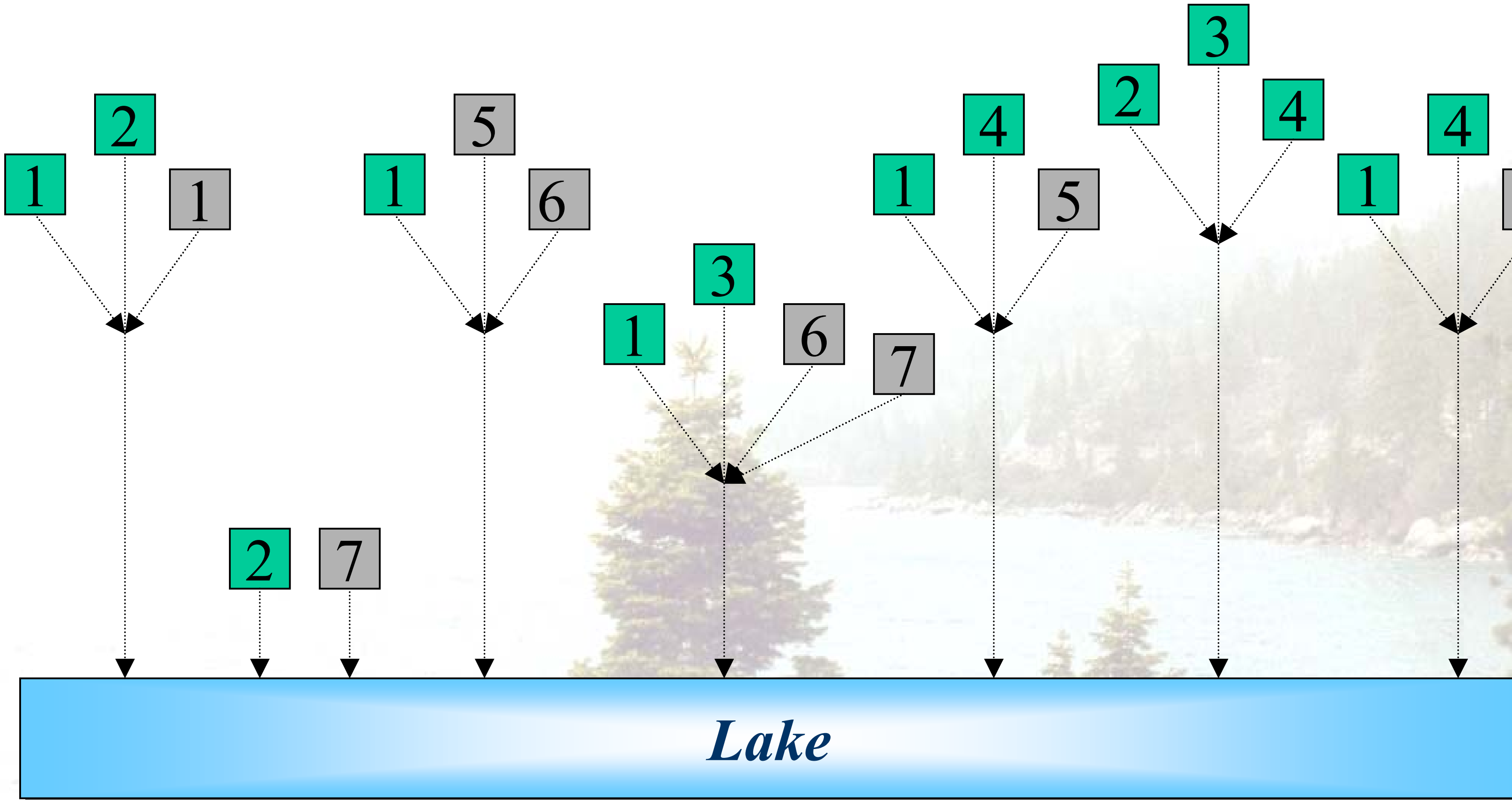
- Subwatershed delineation
  - Full basin for TMDL analysis (existing Tahoe subwatersheds)
  - Site-level for calibration (monitoring site delineations)
- Landuse category selection

Subwatershed Delineation

- Subdivision of the watershed intro discrete components
- Delineation based on:
  - elevation (topographic data)
  - stream connectivity
  - location of flow and water quality monitoring stations
- Each subwatershed is modeled with 1 representative stream
  - streams are assumed trapezoidal
- Each subwatershed is modeled with 1 representative meteorological time series

Land Simulation

- Each subwatershed is represented by multiple land units (based on landuse coverages)
- Land units are either pervious or impervious
- Model algorithms are run for each individual land unit

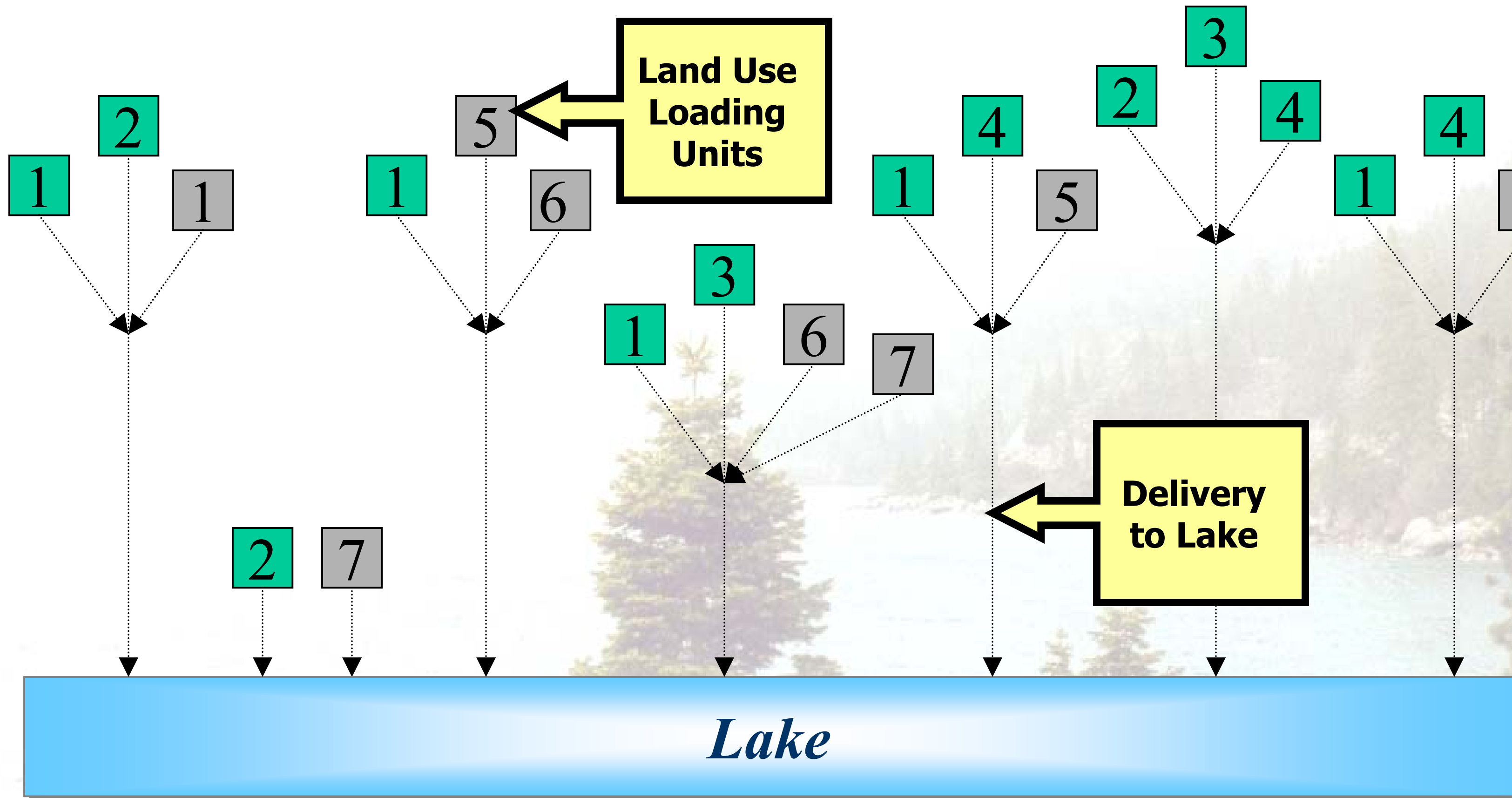


Watershed Loading Schematic

- *Tributaries converging to discharge to lake*
- *Direct drainage to lake*

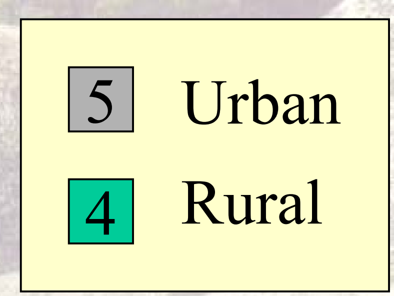
5 Urban

4 Rural



Watershed Loading Schematic

- *Tributaries converging to discharge to lake*
- *Direct drainage to lake*



2 Scales of Delineation

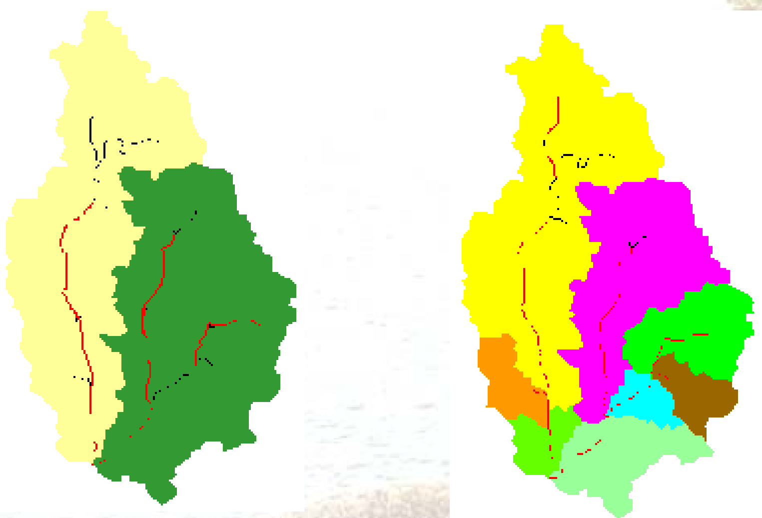
1. Subwatershed delineation for calibration to historical and ongoing monitoring sites
2. Subwatershed delineation for entire Tahoe Basin

- Calibrated model parameters from the calibration subwatersheds will be validated at a larger scale using the entire Tahoe Basin subwatershed distribution

Subwatershed Delineation

- Need to define a suitable level of segmentation
- Consistent with other research

Lumped → Distributed



2 Segments ***8 Segments***

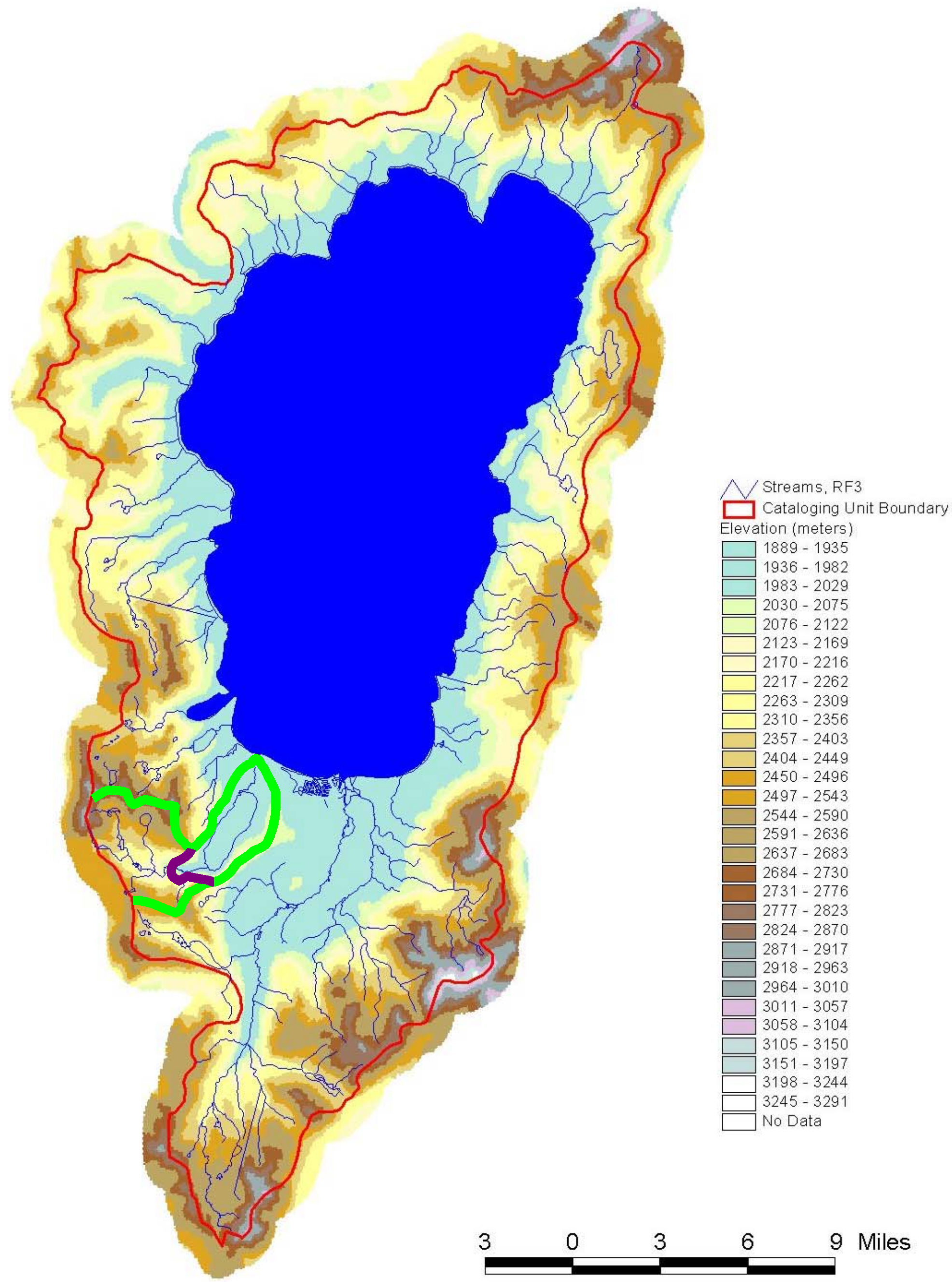
Factors to Consider

Watershed
- Land use/Sources
- Soils
- Topography/elevation
- Weather station location
- Monitoring points
- Existing management

Management
- Planning
- Regulatory
- Impact
- Alternatives analysis

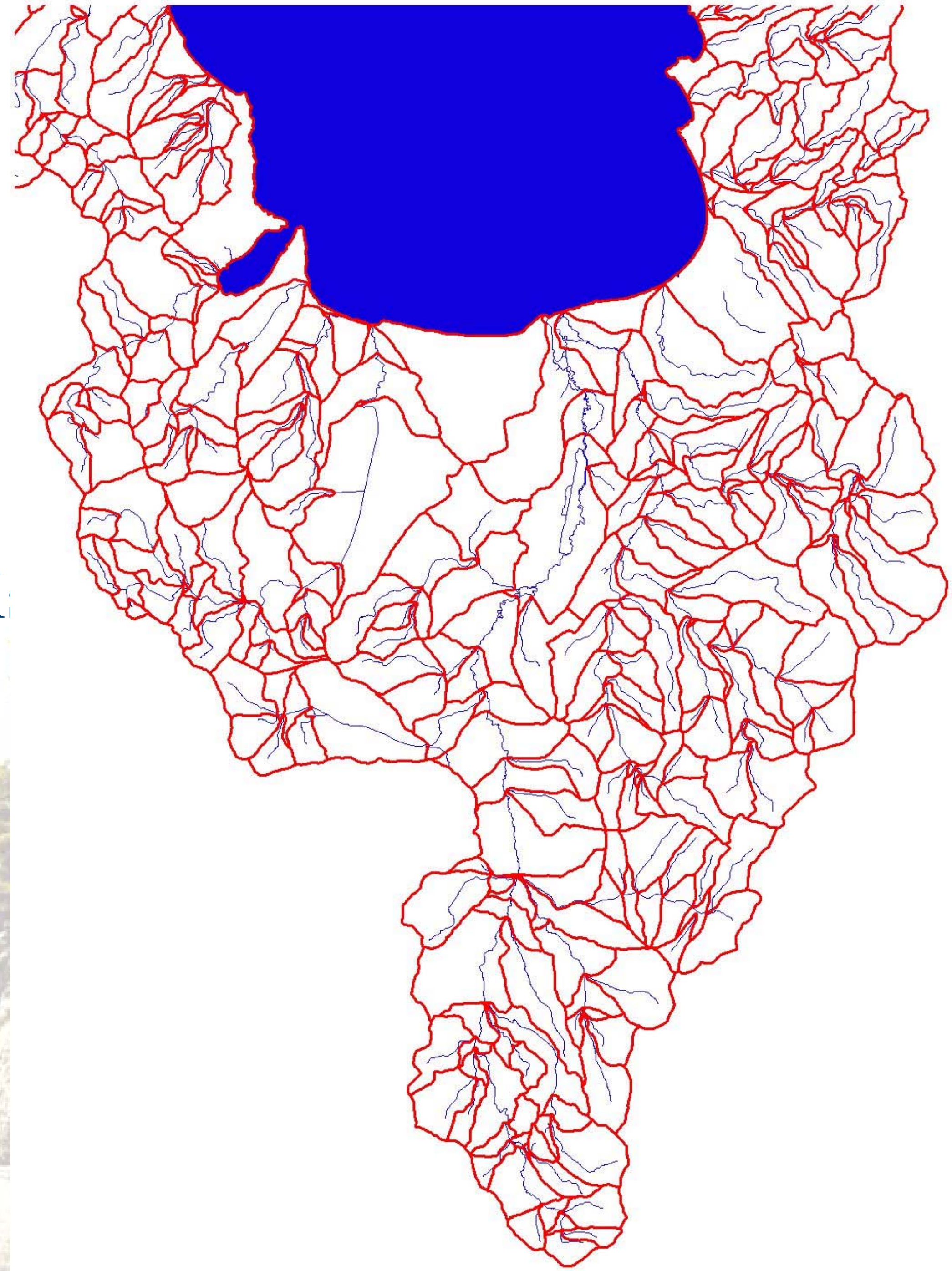
Elevation Considerations

- Subdivide incoming stream basins based on elevation
- Impacts hydrology processes (snowmelt and atmospheric variability with elevation)



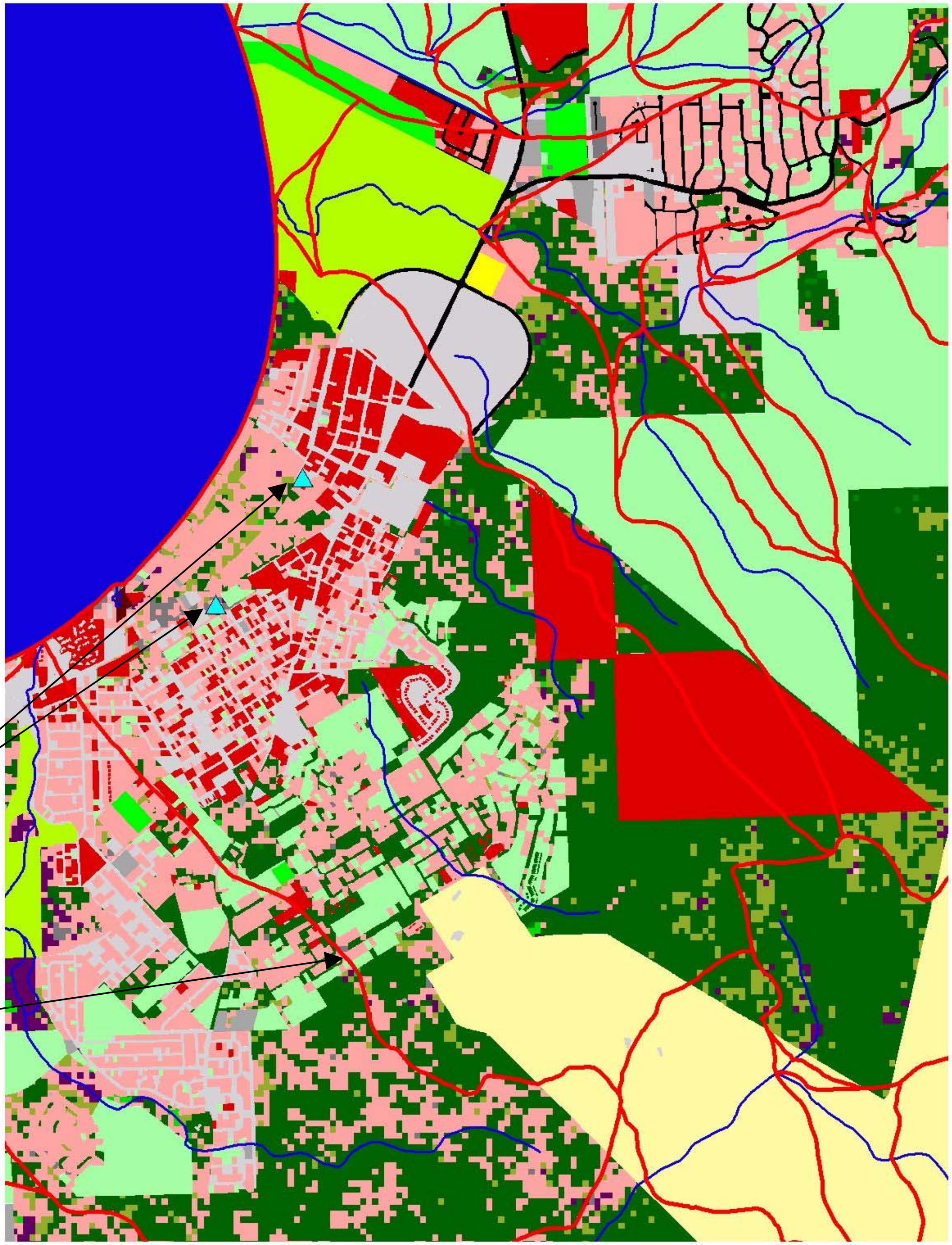
Existing Coverages

- 597 subwatersheds in TRPA coverage
- Each stream segment i
subdelineated
- Possible starting point
(will likely aggregate many individual subwatersheds)



Calibration Delineations

- Different scale than for full-basin analysis



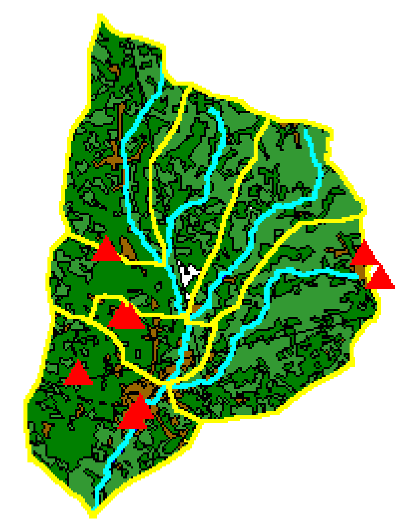
Stormwater Monitoring Sites

Existing Subwatershed Coverage

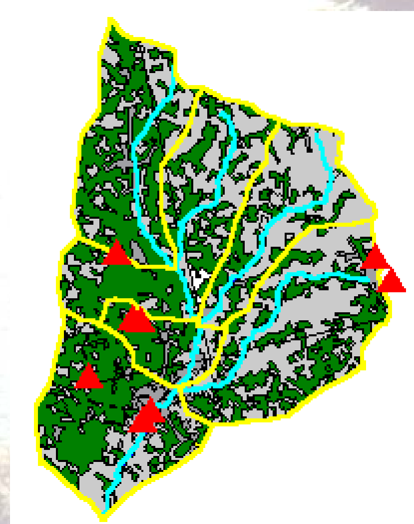
Landuse Selection

- What is the suite of land use categories that will be described individually?

Lumped → Distributed



Anderson Level 1



Anderson Level 2

Factors to Consider

- **Predominant Landuse**
- **Type of Impacts**
- **Management categories**
- **Future Land Use Conversion**
- **Data Availability**
- **Resources**

Categorization for SW Monitoring

- Single family residential – 5 sites
- Multi family residential – 2 sites
- Commercial – 1 site
- Communications/utilities – none (minimal area)
- Institutional – none (minimal area)
- Agriculture/livestock – none (minimal area)
- Transportation – 6 CalTrans sites
- Recreation/open space – 1 site
- Mixed urban – 2 sites
- Bare – none (minimal area)
- Vegetated – 4 sites (1 completely vegetated, others are divided with urban categories)

Draft Landuse Categories

- Residential
  - Single family residential
  - Multi family residential
- Commercial
- Mixed urban (including communications, institutional)
- Transportation
  - Primary roads
  - Secondary roads
- Recreation/open space/bare
- Vegetated
  - Undisturbed
  - Moderately disturbed
  - Highly disturbed
  - Burned zones

Hydrology Model Development

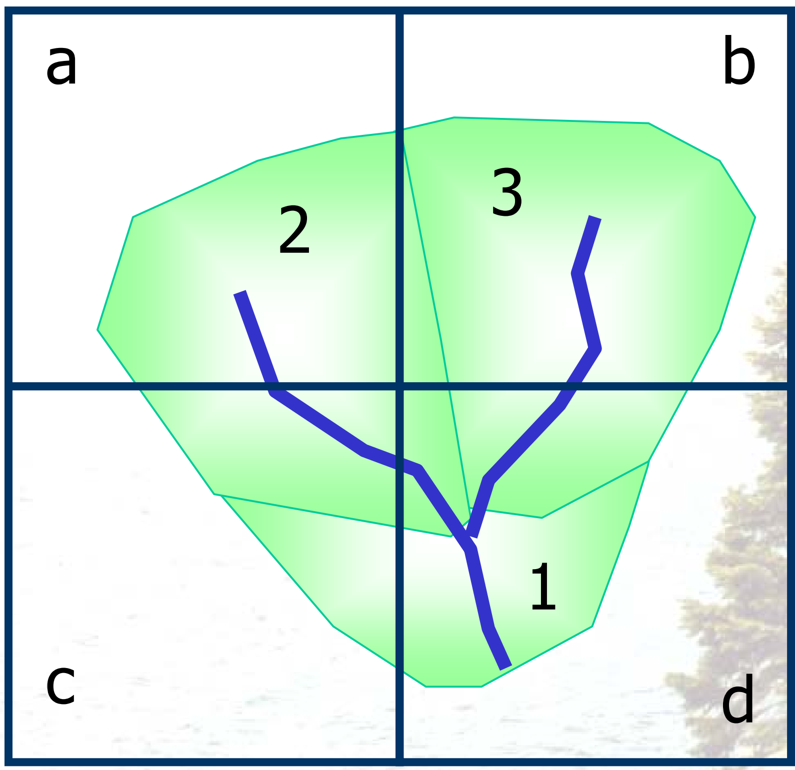
TASK	2002		2003				2004				2005			
	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
1. Hydrology Model Development														
1.1 Subwatershed Delineation														
1.2 Meteorological Data Processing														
1.3 Calibration														

Data Needs:

- Meteorological grid
- Hourly time series data files (at ground surface), preferably in text files

  Either complete or partial example dataset

Meteorological Data Processing



Subwatershed

3 km meteorological grid

Subbasin Area-Weighting

- Subbasin 1 =

  $0.4\ c + 0.6\ d$

- Subbasin 2 =

  $0.4a + 0.1b + 0.3c + 0.2d$

- Subbasin 3 =

  $0.7\ b + 0.3\ d$

Weather Data Application

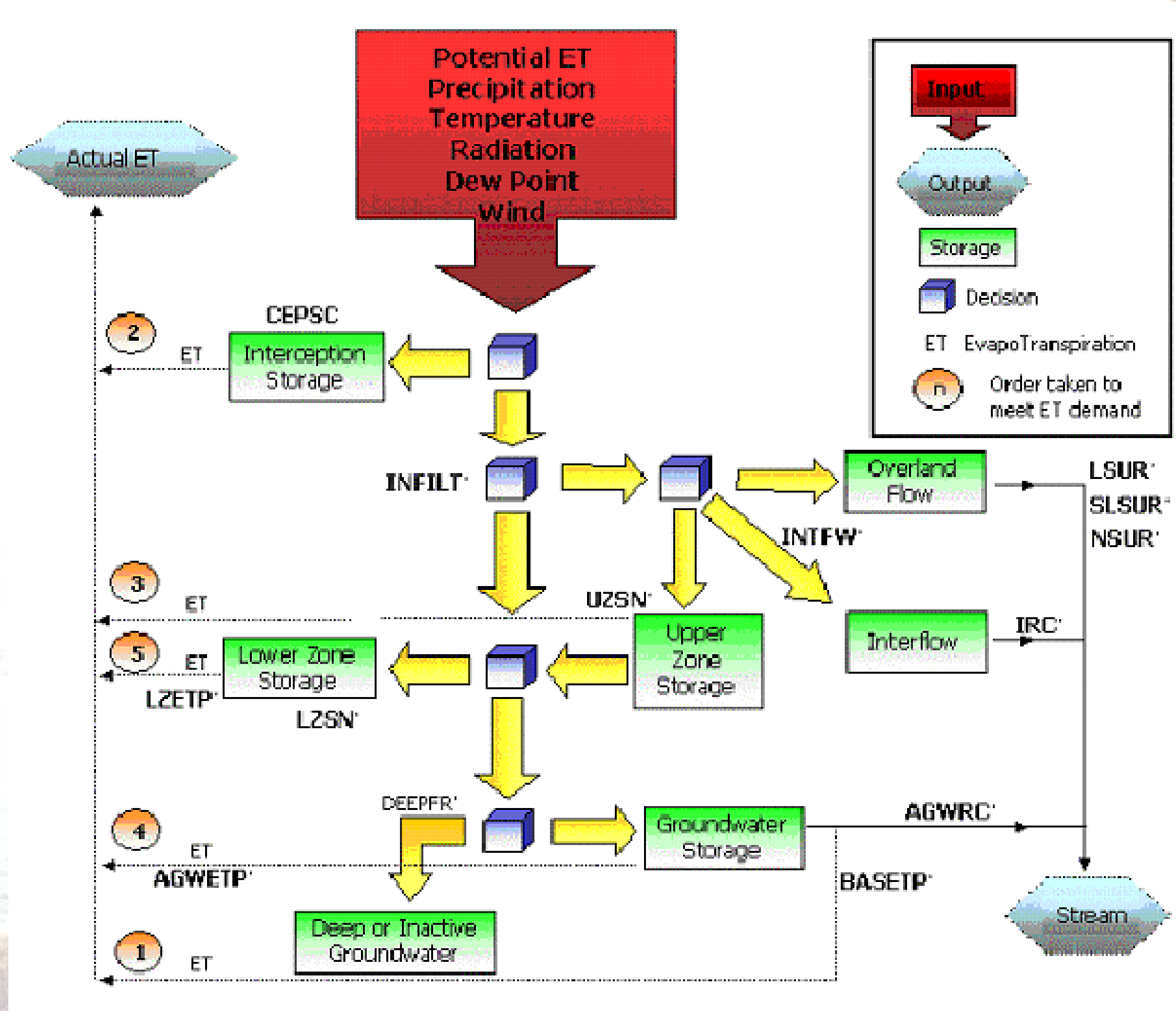
	Land					Reaches		
	Temp	Snow	Water	Sediment		Water	Heat	Gen. Qual.
Precipitation	●	●	●	●		▲	▲	
Pot. ET			●	●		▲		
Air Temperature	●	●					●	
Wind Speed		●					●	●
Solar Radiation		●					●	
Dewpoint Temp.		●					●	
Cloud Cover							●	●

● Required

▲ Optional

Hydrology

- Hydrologic Components:
  - Precipitation
  - Interception
  - Evapotranspiration
  - Overland flow
  - Infiltration
  - Interflow
  - Subsurface storage
  - Groundwater flow
  - Groundwater loss



Source: Stanford Watershed Model

Land Simulation Considerations

Land Simulation

WATER | ATEM | SNOW

TWO POSSIBLE METHODS:

- Energy Balance
  - COE, 1956; Anderson Crawford, 1964; Anderson, 1968
- Temperature Index or “Degree-day”
  - Rango and Martinec, 1995

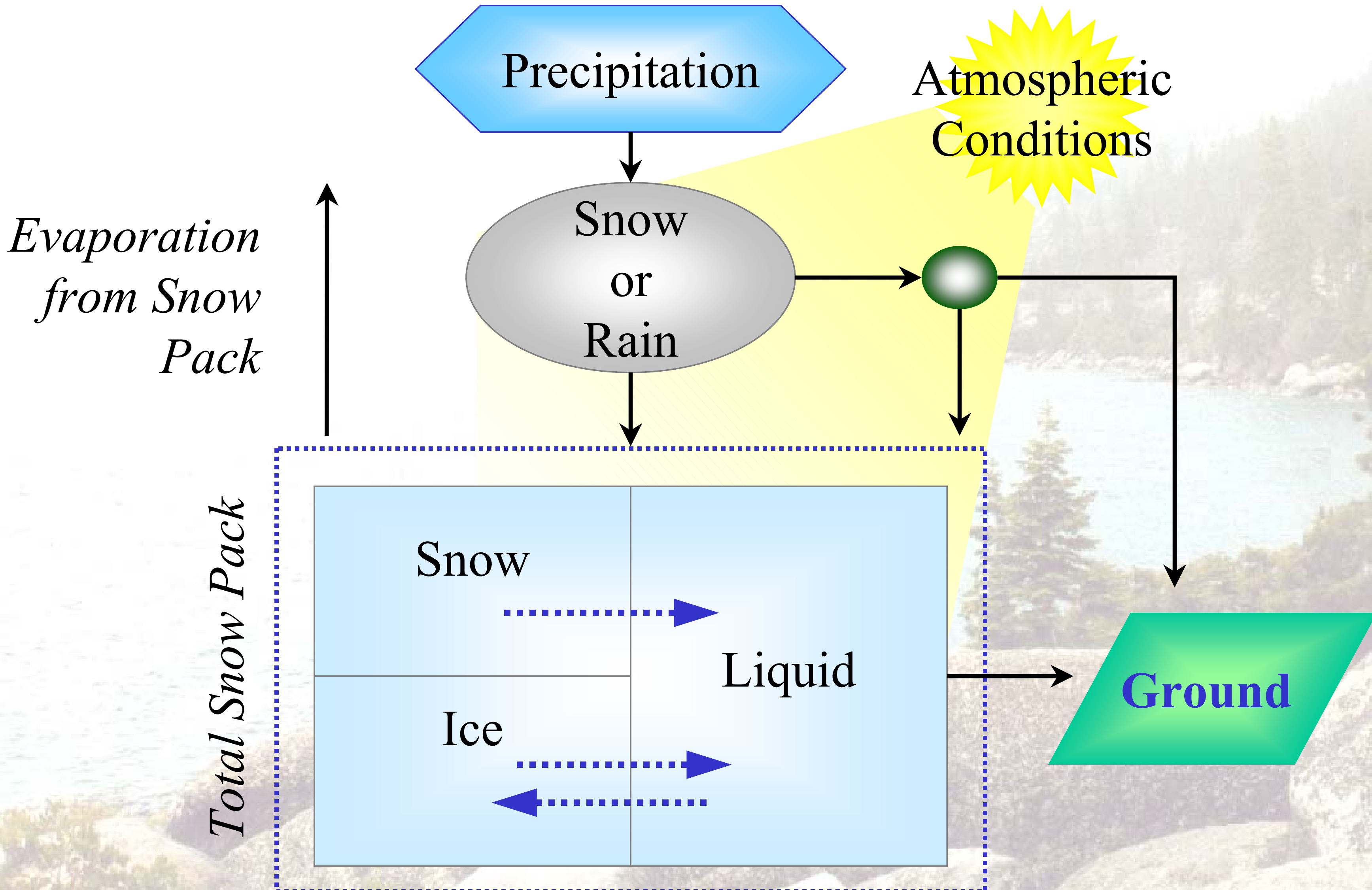
Land Simulation Considerations

Land Simulation

WATER | ATEM — SNOW

Weather Data	Energy Balance	Degree Day
Precipitation	**Required**	**Required**
Air Temperature	**Required**	**Required**
Solar Radiation	**Required**	Not Used
Dewpoint	**Required**	*optional*
Wind Speed	**Required**	Not Used
Cloud Cover	*optional*	Not Used

Snowmelt Schematic



Components of Hydrograph

Runoff

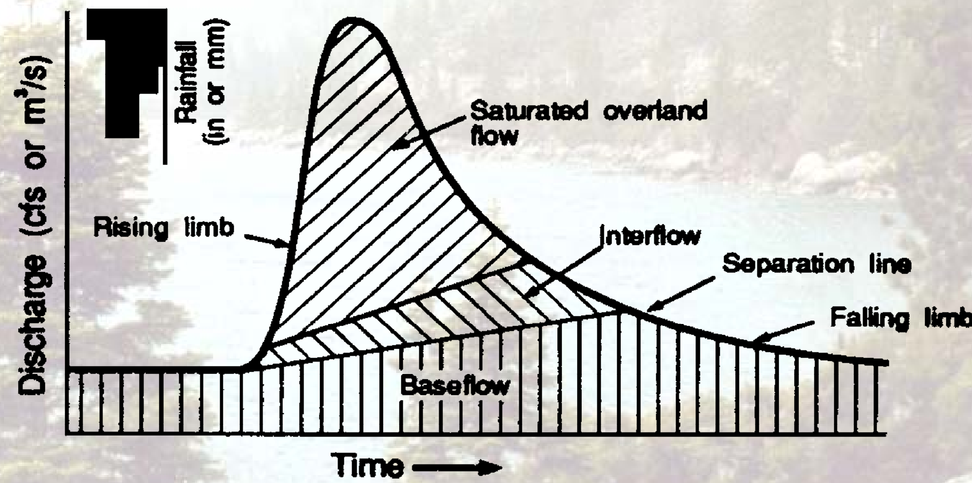
Interflow

Baseflow

Surface runoff - overland flow

Interflow - flow through surficial layers of soil

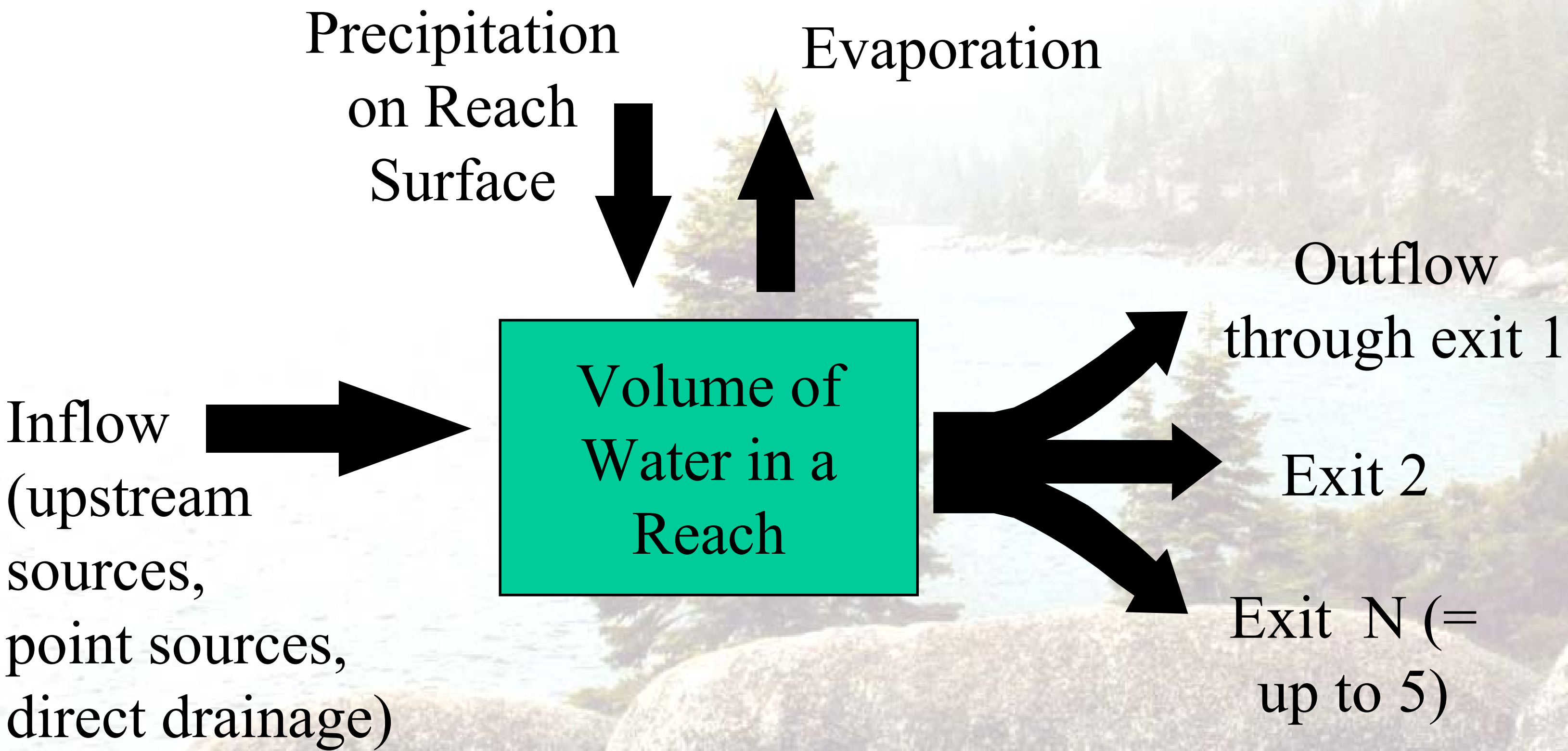
Baseflow - groundwater seepage from springs and
aquifers directly to the stream channel



Stream Hydraulics

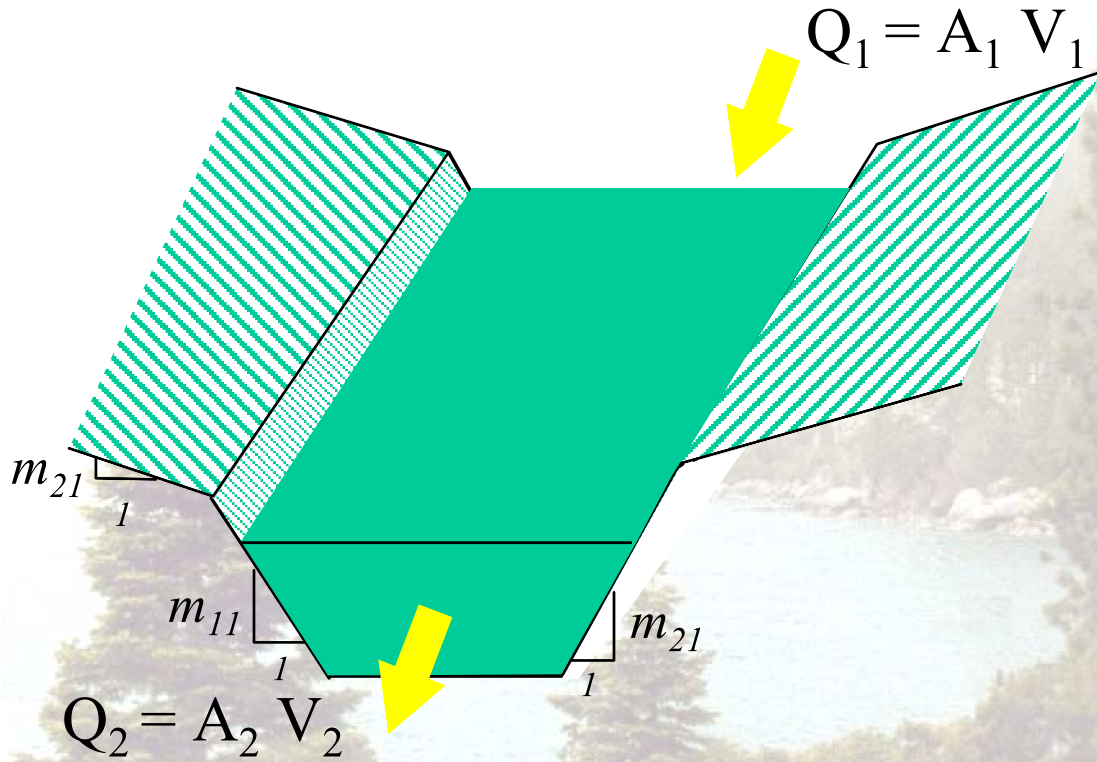
- Completely mixed reach (single layer)
- Unidirectional flow
- Flow routing by kinematic wave or storage-routing method (i.e. conservation of momentum not considered)
- Requires function table (FTable) for depth-volume-discharge relationship for each reach.
- Precipitation/evaporation accommodated
- Calculates outflow, depth, volume, surface area, and selected auxiliary variables (velocity, cross-sectional area, bed shear velocity/stress)

Flow Diagram for HYDR Section of RCHRES



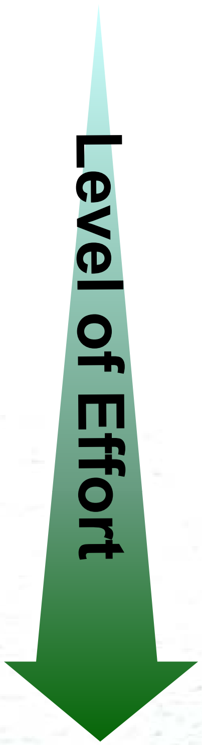
Function Table

- Area (surface) = Top width * length
- Volume = Cross sectional area * length
- Outflow can be withdrawal, spillway discharge or outflow at the downstream end of a reach
- Stream Flow = Cross sectional area * velocity

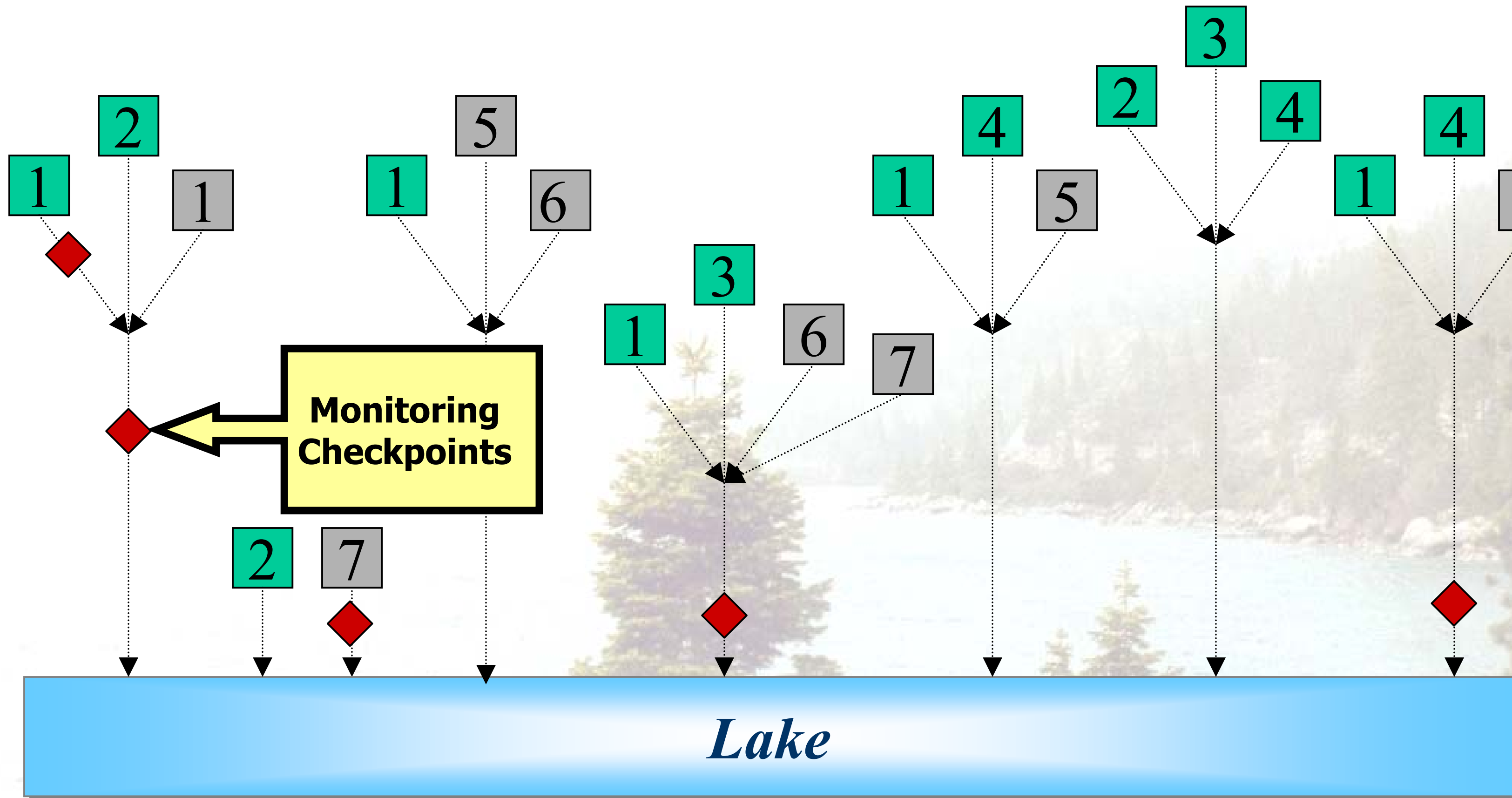


Depth	Area	Volume	Outflow
0.0	0.0	0.0	0.0
0.08	10.81	0.86	2.12
0.80	11.36	8.84	98.09
1.20	11.68	13.45	192.51

Hydrology Calibration

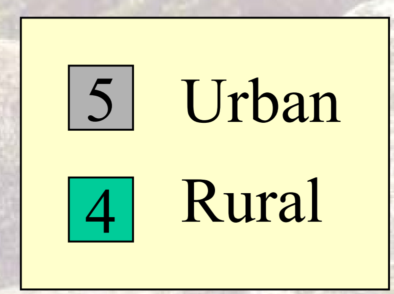


- Analytical Considerations
  - Annual water balance
  - Seasonal / monthly distribution
  - Distribution of hydrograph components
    - Storm flow
    - Base flow
  - Snowfall / snowmelt influence



Watershed Loading Schematic

- *Tributaries converging to discharge to lake*
- *Direct drainage to lake*

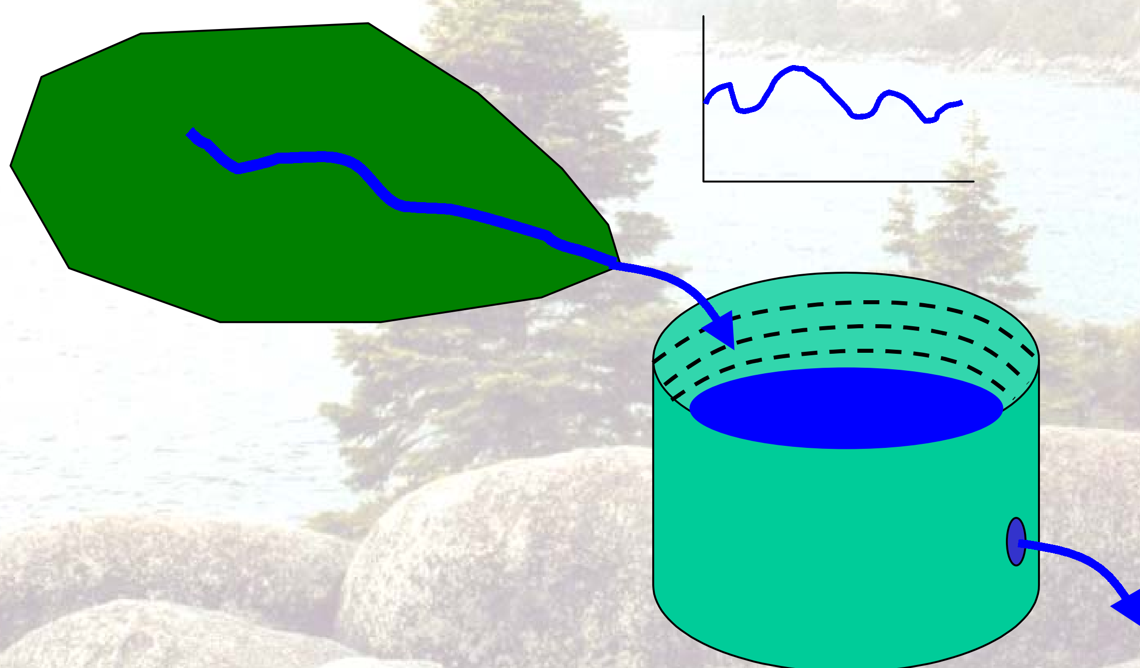


Hydrology Calibration Methods

- Hourly/Daily/Monthly Timeseries
- Monthly Scatter/Balance Plots
- Seasonal Plots (Multi-Year Composites)
- Flow Duration Curves
- Flow Accumulation Curves
- Cumulative Error Statistics
- Hydrograph Components

Issues With the Water Balance

- Fine-tuning the watershed model minimizes the propogation of error in the reservoir



Sediment Model Development

TASK	2002		2003				2004				2005			
	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
2. Sediment Model Development														
2.1 Data Compilation														
2.2 Model Formulation Selection														
2.3 Calibration														

Key considerations and data needs:

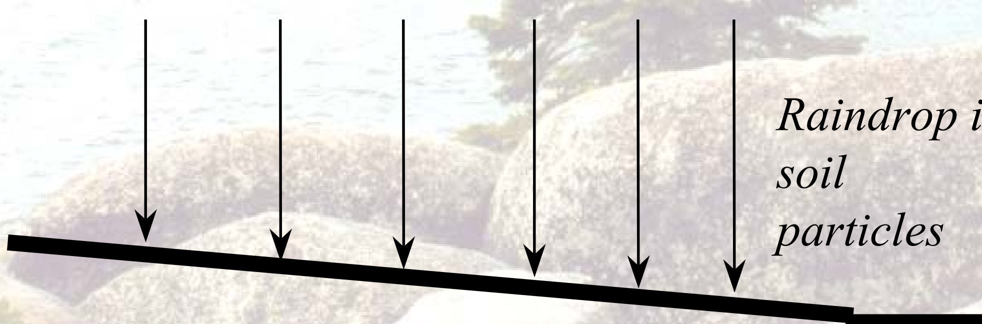
- Bank erosion versus upstream loads (CONCEPTS/AGNPS results)
- Particle-size distribution

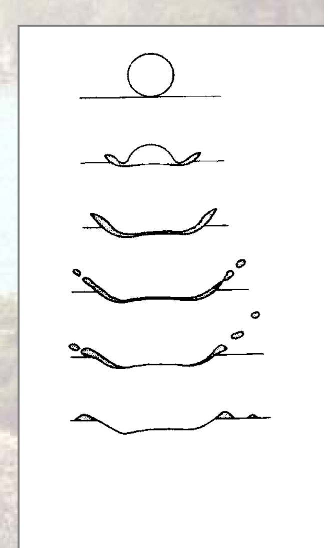
Sediment Load Estimation

- 2 potential options
- Option 1 (first phase of modeling)
  - Use LSPC algorithms for land erosion and sediment transport to predict overall sediment load
  - Represent suite of particle sized
- Option 2 (second phase)
  - Assuming significant channel erosion is identified through CONCEPTS/AGNPS modeling, incorporate channel erosion component in watershed model

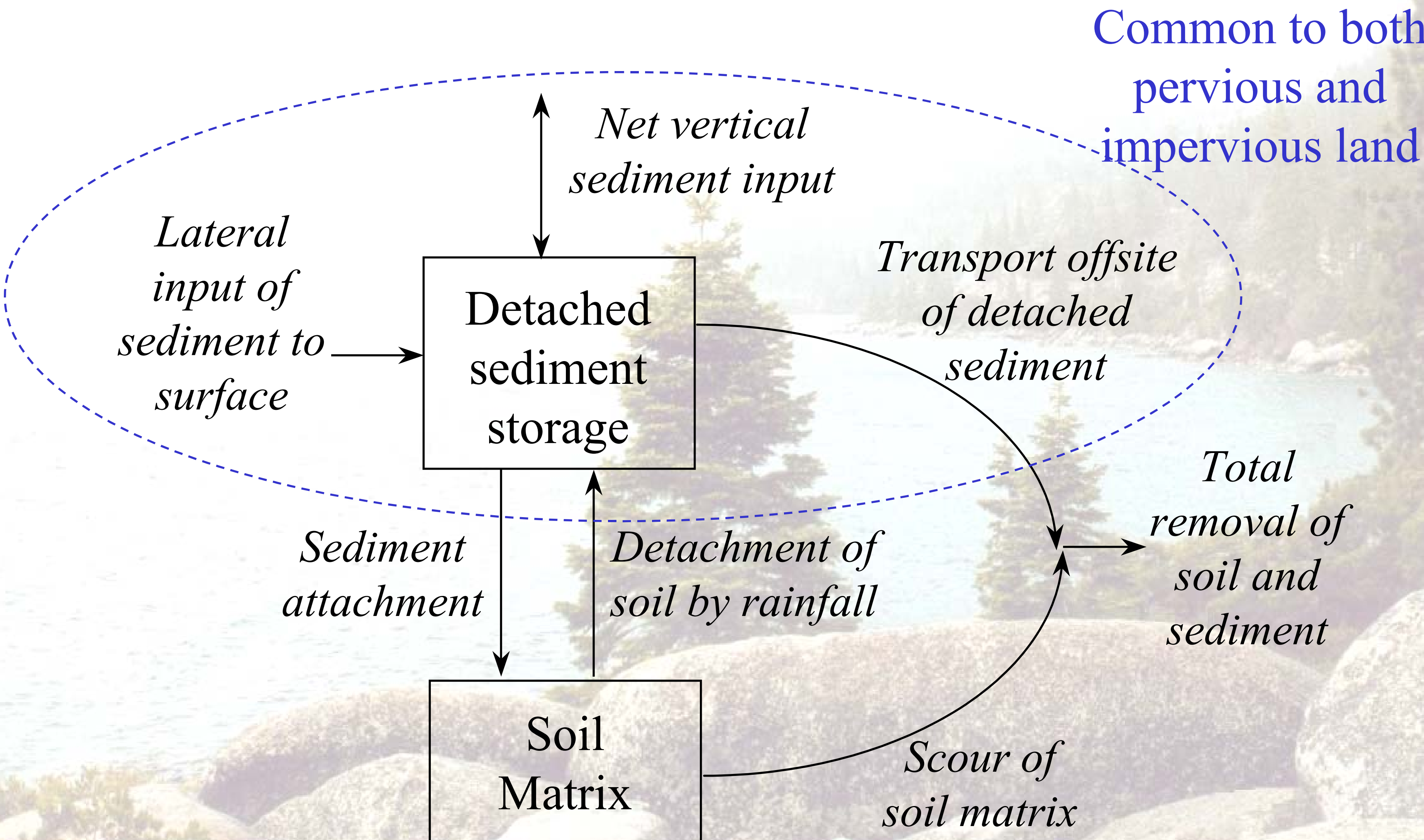
Erosion and Sediment Processes

- Pervious land areas
  - Erosion is a function of land use activity, soil characteristics, slope, land cover, and precipitation
  - Erosion occurs due to rainfall “energy”
    - Detachment of soil particles
    - Washoff of detached material





Sediment Processes



Sediment Budget and Transport

- Land Processes
  - Production and removal of sediment from land
    - Washoff of loose sediment
    - Scouring of soil matrix
- Stream Channel Processes
  - Transport, deposition and scour of sediment in the stream channels

Nutrient Model Development

TASK	2002		2003				2004				2005			
	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
3. Nutrient Model Development														
3.1 Data Compilation														
3.2 Model Formulation Selection														
3.3 Calibration														

Key considerations and data needs:

– Groundwater baseflow concentrations

– Land use specific nutrient information

Overland Water Quality Processes

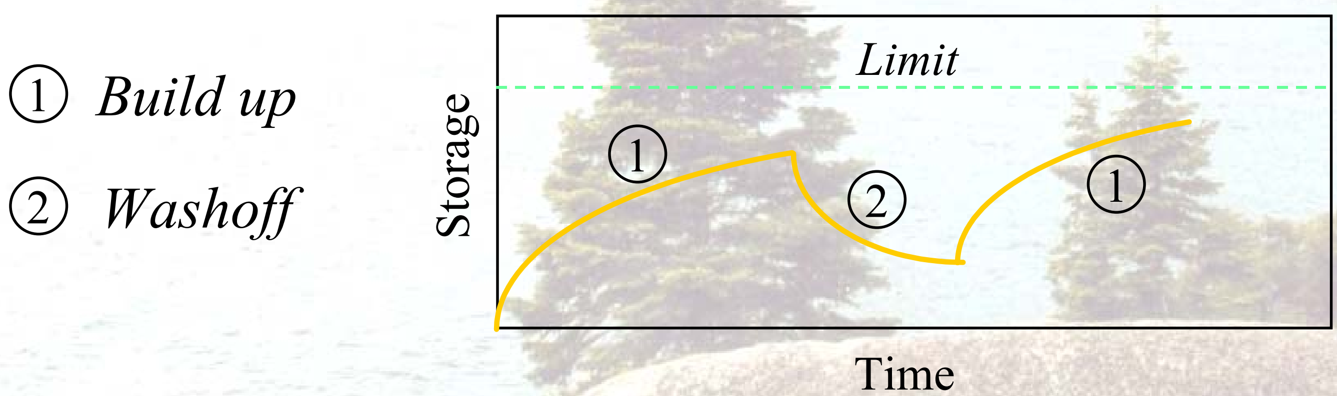
- Urban Land Units
  - Impervious areas
    - Dust and dirt build-up functions
  - Pervious areas
    - Dissolved pollutants with runoff
    - Erosion and adsorbed pollutants with sediment
- Rural Land Units
  - Erosion and adsorbed pollutants with sediment
  - Dissolved pollutants with runoff

Overland General Quality (Rainfall-driven processes)

- Build-up
- Washoff

Constituent Build-up

- Accumulation at a constant rate for a constituent
- Computed at daily time interval



Change of storage with time

In-stream Simulation of Generalized Quality Constituent

- **Simulates dissolved and sediment associated general quality constituents**
- **Processes applicable to dissolved general quality constituents include:**
  - **Advection of dissolved material (dominant process in the watershed)**
  - **Decay processes (1st order decay used to represent net nutrient losses attributed to settling, transformations, etc.)**

Model Refinement and Verification

TASK	2002		2003				2004				2005			
	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
5. Model Refinement and Verification														
5.1 Model Refinement - Nutrients														
5.2 Model Refinement - BMPs														
5.3 Verification														

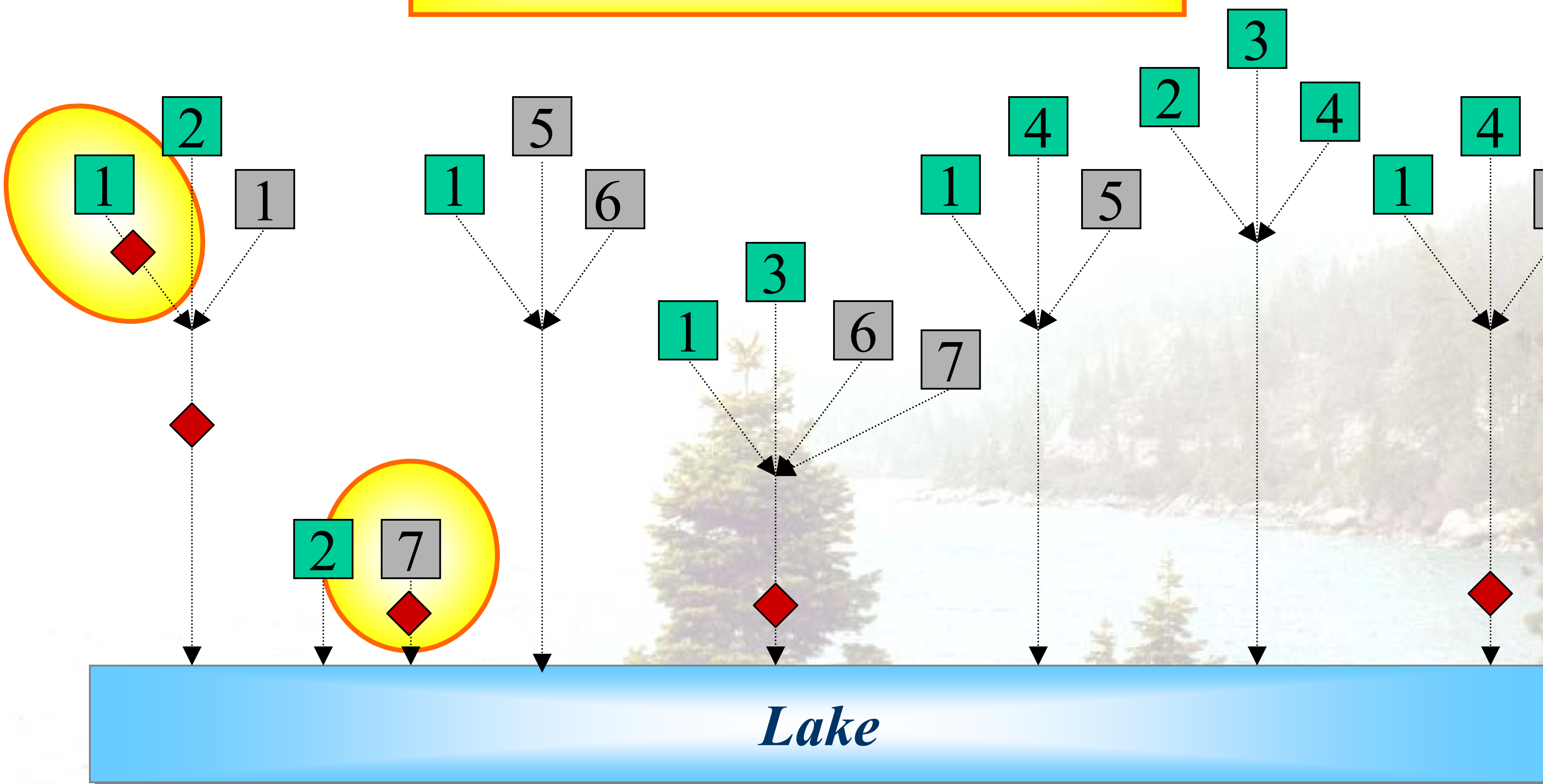
Sediment Load Estimation Update

- Incorporate CONCEPTS/AGNPS results using stream reconnaissance:
  - Explicit simulation of channel erosion processes, e.g. extend CONCEPTS model to simulate all remaining streams in the basin or incorporate CONCEPTS algorithms into LSPC
  - Empirical formulations using CONCEPTS results, e.g. application of derived rating curves

Reconciliation with Statistical Analysis…Options

- Selected replacement of HSPF sediment and nutrient loading algorithms with statistically-derived equations
- Application of statistically derived EMCs or landuse-based rating curves to watershed model-predicted flows
- Use statistical results as a confirmation/validation tool for the watershed model

Land Use Calibration Points



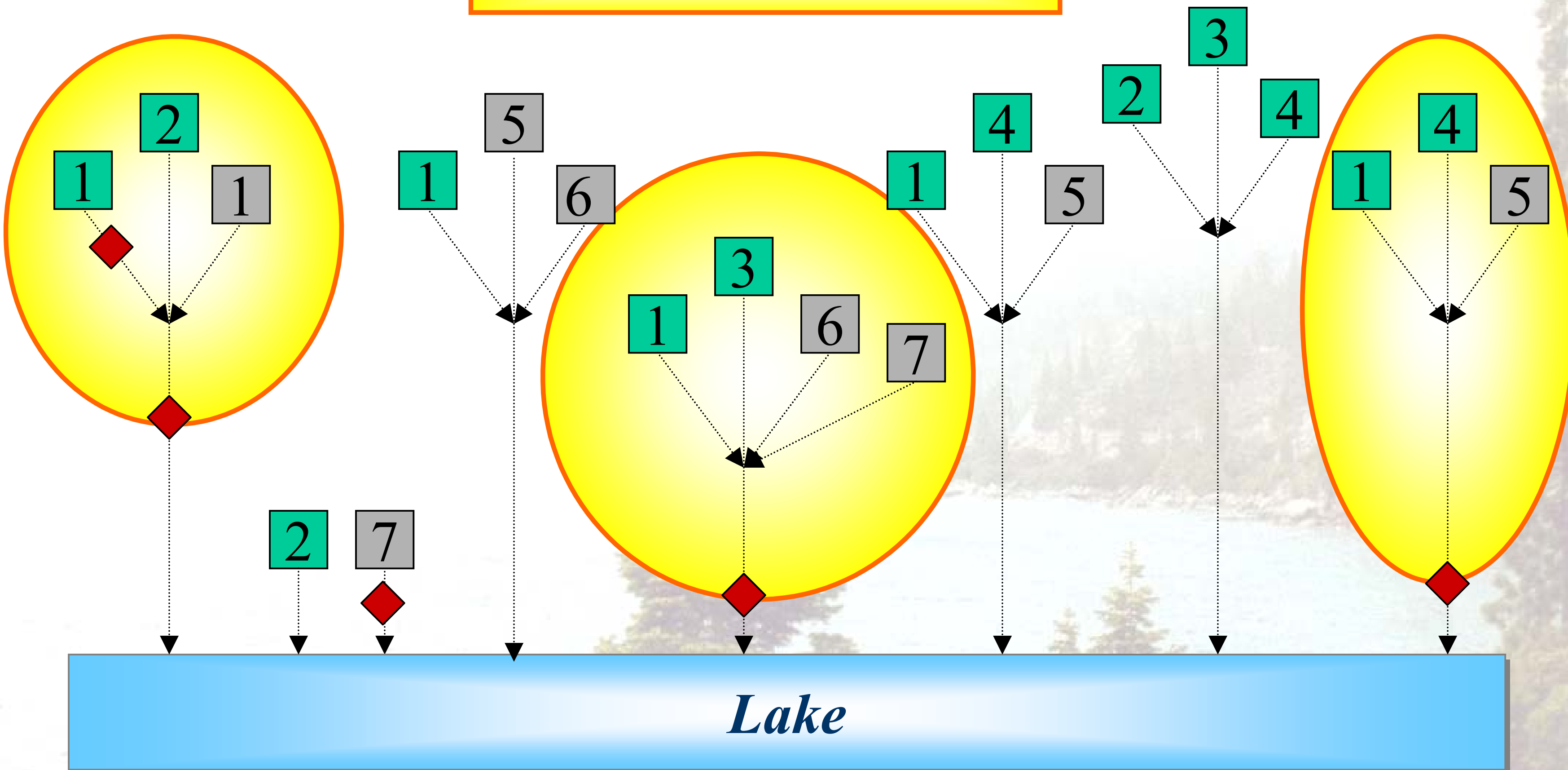
5 Urban

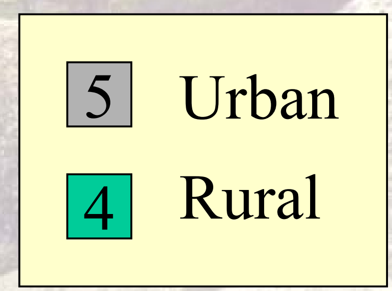
4 Rural

Data Needs:

- *Monitoring site delineations*
- *Lake Tahoe subwatershed delineations*

Validation Points





Data Needs:

- *Monitoring site delineations*
- *Lake Tahoe subwatershed delineations*

Watershed Model Results

- Reach Output
  - Hourly flow and nutrient concentrations at downstream end of each reach
  - Cumulative results
- Land Unit Output
  - Hourly flow and nutrient loads for each land unit in each watershed
  - Evaluate contributions at the source level

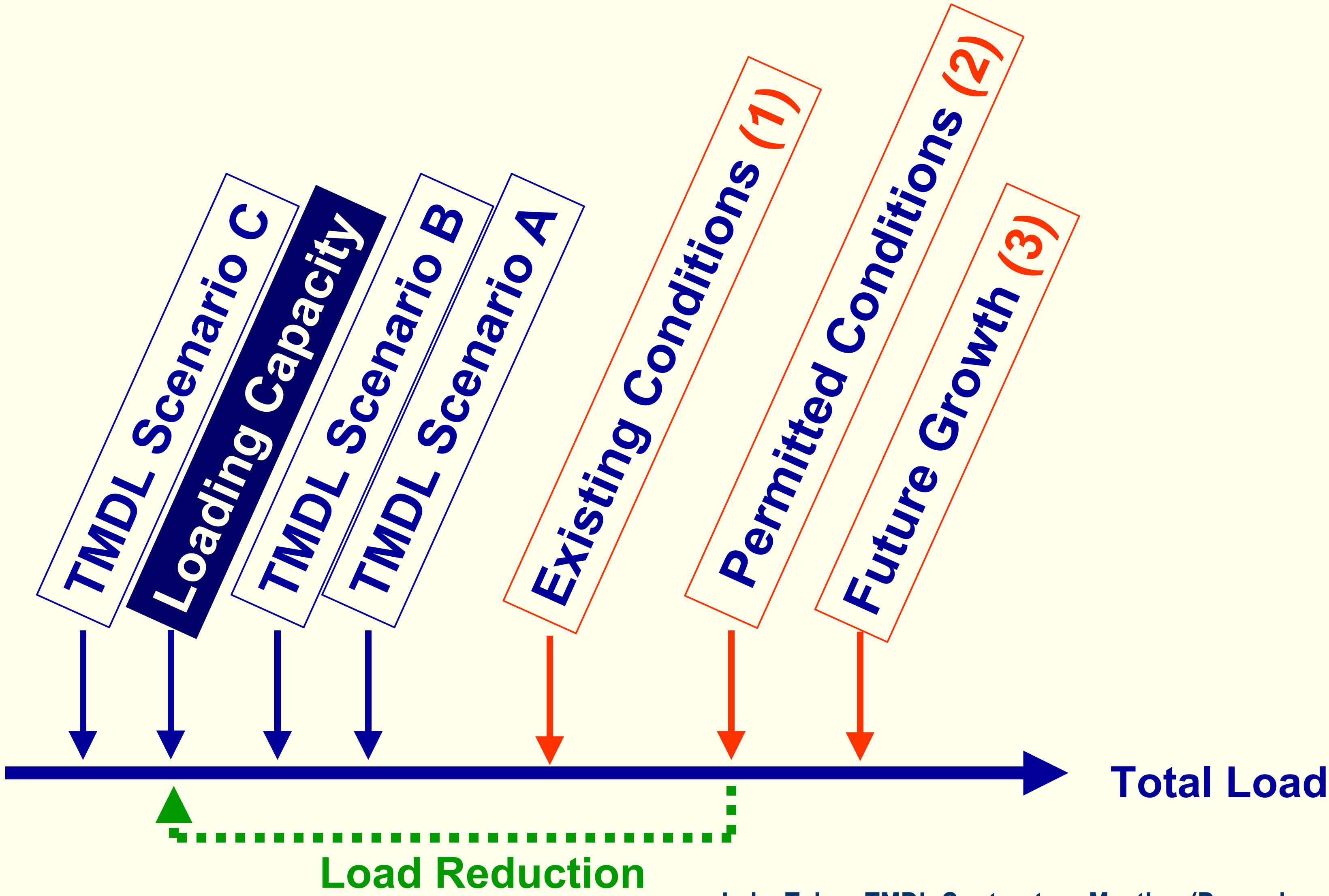
TMDL Analysis Considerations

Loading Capacity for Lake to meet target(s)

Potential Load Reduction based on Management Opportunities.

Potential Load Reductions under Various Scenarios

Allocation Steps



TMDL Analysis Considerations

Loading Capacity for Lake to meet target(s)

Selected Load Allocation

TMDL

Potential Load Reductions under Various Scenarios

Future Planning Support

Implementation

Potential Load Reduction based on Management Opportunities.